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all important publications that have appeared recently.

The second journal, *The International Journal of American Linguistics*, is edited by F. Boas and Pliny E. Goddard, with the assistance of Professor Uhlenbeck, of Leiden, and Dr. W. Thalbitzer, of Copenhagen. The first number of the journal contains a brief introduction setting forth the object of the journal. Special articles which have so far appeared deal with the languages of Central America and North America. In the reviews a summary of work done by the Bureau of American Ethnology is given.

F. B.

#### SPECIAL ARTICLES

##### THE RELATION OF THE PLANT TO THE REACTION OF THE NUTRIENT SOLUTION

ONE of the important factors to be considered in plant nutrition studies is the reaction of the nutrient solution. The determination of H ion concentration is of value, not only because of its general relation to plant growth, but also because of its bearing on the nature of selective absorption of ions. At the present time various misleading statements exist in the literature with regard to these points. In many cases principles which are elementary to the physical chemist have not been sufficiently appreciated by the agricultural chemist. In the course of extended studies conducted by this laboratory to determine some effects of concentration of the nutrient solution on plant growth and absorption, opportunity has been afforded for ascertaining the exact reaction of the nutrient media under widely varying and carefully controlled conditions. The purpose of the present article is the discussion in a preliminary way of this phase of the investigation.

It is a quite common impression that the plant by selective absorption may so alter the reaction of the nutrient solution as to produce extreme alkalinity or acidity. For example, Palladin<sup>1</sup> in describing water culture experiments states:

<sup>1</sup> Palladin, W., "Pflanzen physiologie," Berlin, 1911, p. 82.

Während der Vegetation muss dafür gesorgt werden, dass die Kultur flüssigkeit nicht alkalisch wird. Zur Beseitigung der alkalischen Reaktion wird so lange schwache Phosphorsäurelösung zugesetzt, bis die Lösung schwach sauer reagiert.

Also it is often claimed that from KCl, K<sub>2</sub>SO<sub>4</sub>, and similar solutions the cation is removed at a rate so much faster than that of the anion that a marked acid reaction ensues, which may result in injury to the plant. Conversely a NaNO<sub>3</sub> solution is said to become alkaline. The evidence on which these ideas are based is very slight. Some of the experiments quoted were performed many years ago, when chemical methods and principles were in a relatively imperfect stage of development. The condition of acidity or alkalinity in most of the investigations has been measured by various titrations, which for this purpose are subject to misinterpretation, as pointed out in a previous article.<sup>2</sup>

In the latter investigation experiments with barley seedlings indicated a strong tendency on the part of the plant to change the reaction of various potassium phosphate solutions in the direction of neutrality; either acid or alkaline solutions soon attained a H ion concentration equivalent to approximately Ph 7.0, while neutral solutions remained unaltered in reaction. These experiments have now been extended to other solutions including complete nutrient solutions, and observations have been made at all stages in the growth cycle of the barley plant. Also several varieties of beans have been used. The experiments were carried out by means of sand and water cultures, which will be described elsewhere. It will suffice to state here that the technique was such as to permit of the production of normal, well matured plants. In every instance, without exception, nutrient solutions with an acid reaction reached an approximately neutral reaction after contact with the plant roots for varying periods of time. Even where plants were grown to maturity without change of solution, the neutral

<sup>2</sup> Hoagland, D. R., "Soil Science," Vol. III., No. 6, pp. 547-560, 1917.

reaction remained constant throughout the entire period. The data from a number of typical experiments are presented below. H ion concentrations were usually determined colorimetrically, with the methods and indicators described by Clark and Lubs.<sup>3</sup>

TABLE I

Description of Plant	Solution	Time of Contact	Reaction at Beginning, $P_H$	Reaction After Contact with Plant, $P_H$
Barley grown to maturity. No change of solution	Complete nutrient 1500 p.p.m.	4 mos.	6.8	6.9
Barley 6 weeks	Complete nutrient 2500 p.p.m.	1 week	5.6	6.8
Barley 7 weeks	Complete nutrient 1500 p.p.m.	22 hrs.	5.1	6.1
Barley 7 weeks	Complete nutrient 1500 p.p.m.	36 hrs.	5.1	6.8
Barley 7 weeks	Complete nutrient 5000 p.p.m.	50 hrs.	5.0	6.1
Barley 7 weeks	Complete nutrient 5000 p.p.m.	96 hrs.	5.0	6.5
Barley grown to maturity	Complete nutrient 300, 1000, 2500 p.p.m.	12 weeks	6.8	6.5-7.2

Chemical analyses of the solutions made it clear that the change in reaction had been the result of selective absorption from the various phosphoric acid anions, accompanied by an equivalent removal of positive ions. A marked regulatory absorption is apparent.

Other experiments were made in which barley plants were grown for seven weeks in favorable nutrient solutions and then transferred (after thoroughly washing the roots in distilled water) to solutions of KCl,  $K_2SO_4$ ,  $MgSO_4$ ,  $K_3PO_4$ ,  $NH_4Cl$  and  $NaNO_3$ . The reactions of the solutions were tested after varying periods of contact from a few hours to forty days. In no case was a condition either of excessive OH ion or H ion concentration produced, although absorption had been

<sup>3</sup> Clark, W. M., and Lubs, H. A., *Jour. Biolog. Chem.*, Vol. XXV, No. 3, pp. 479-510, 1916.

active. The acid reaction when present was due to slightly dissociated acids, usually carbonic, or to acid salts in the case of the  $NH_4Cl$  solution. Possibly in some cases organic acids were formed.

TABLE II

Salt Used. (Concentration 1,500 p.p.m.)	Time of Contact	Per Cent. of Salt Absorbed (by Con- ductivity)	Reaction After Contact, $P_H$	Reaction Solution After Heating, $P_H$
KCl . . . . .	39 days	42.6	5.3	6.5
NaNO <sub>3</sub> . . . . .	39 "	56.5	7.2	9.5
MgSO <sub>4</sub> . . . . .	16 "	22.9	6.5	7.0
K <sub>2</sub> SO <sub>4</sub> . . . . .	16 "	36.8	6.3	7.0
K <sub>3</sub> PO <sub>4</sub> <sup>(1)</sup> . . . . .	16 "	33.0	7.5	—
NH <sub>4</sub> Cl <sup>(2)</sup> . . . . .	8 "	30.0	5.0	—

$P_H$  original solutions (1) 10.3, (2) 5.7.

Barley plants grown seven weeks in complete nutrient solutions.

Very striking is the change induced in the  $K_3PO_4$  solution. From a condition of intense alkalinity the solution became approximately neutral. The  $NH_4Cl$  solution retained an acid reaction. This would necessarily be the case as long as any  $NH_4Cl$  remained unabsorbed. The H ion concentration was slightly increased after contact with the plant, but less than would occur if even 1 p.p.m. of residual HCl were formed. Analysis of the solution showed a considerable absorption of both ions, but about 5 per cent. more  $NH_4$  than Cl was removed. The balance was restored, however, by the excretion from the plant of equivalent quantities of other bases, chiefly calcium. There is no evidence that  $NH_4OH$  was absorbed with the formation of a residue of HCl. At least neither the analysis nor the reaction indicates that the absorption took this course.

After boiling the  $NaNO_3$  solution gave an OH ion concentration similar to that produced by the hydrolysis of  $Na_2CO_3$ . The residual solutions of  $NaNO_3$  and KCl were analyzed with the following results.

From the above it may be inferred that part of the  $NO_3^-$  was removed simultaneously with an equivalent quantity of Na, but more  $NO_3^-$  than Na was absorbed,  $HCO_3^-$  ion entering or being formed in the solution to restore the

TABLE III  
*Analyses of Solutions*

	NaNO <sub>3</sub> Solution				KCl Solution			
	At Beginning	After Contact with Plant	Absorption by Plant	Per Cent. Absorption	At Beginning	After Contact with Plant	Absorption by Plant	Per Cent. Absorption
	p.p.m.	p.p.m.	p.p.m.		p.p.m.	p.p.m.	p.p.m.	
Ca . . .	.....	11	.....		.....	14	...	
Mg . . .	.....	...	.....		.....	2	...	
K . . .	.....	.....	.....		1380	812	568	41.1
Na . . .	690	329	361	52.3	.....	.....	.....	
HCO <sub>3</sub> . . .	517	.....	.....		.....	15	...	
Cl . . .	.....	...	.....		1248	732	516	41.3
NO <sub>3</sub> . . .	1860	335	1525	81.9	.....	.....	.....	

Barley plants grown seven weeks in complete nutrient solutions.

Contact with NaNO<sub>3</sub> and KCl solutions 39 days.

balance. This ion in equilibrium with dissolved CO<sub>2</sub> brought about a neutral reaction in the solution actually in contact with the plant. From the KCl solution K and Cl were absorbed in equivalent quantities. On the basis of these results it is clear that the selective action for NO<sub>3</sub>, while it does not of itself cause any injurious reaction, might eventually give rise to an alkaline condition in the soil as a result of the accumulation of Na<sub>2</sub>CO<sub>3</sub>. This is in accord with the usual conception. However, it is not easy to reach the conclusion that KCl, K<sub>2</sub>SO<sub>4</sub>, etc., could bring about an acid reaction in a similar manner. That such a result actually occurs in the soil as the result of salt treatments has been shown by Sharp and the author<sup>4</sup> and by Plummer,<sup>5</sup> but the increase in the intensity of acidity may be ascribed to interreactions in the chemical system of the soil, irrespective of plant absorption.

The extensive analyses of Pantanelli<sup>6</sup> would indicate that in the case of almost every salt, after a few hours contact, the plant has absorbed more of one ion than the other. Nevertheless in the periods of time in question only

<sup>4</sup> Sharp, L. T., and Hoagland, D. R., *Jour. Agr. Res.*, Vol. VII., No. 3, pp. 123-145, 1916.

<sup>5</sup> Plummer, J. K., *Jour. Agr. Res.*, Vol. XII., No. 1, pp. 19-31, 1918.

<sup>6</sup> Pantanelli, E., *Jahrb. f. wissen. Botanik*, Vol. 56, pp. 689-733, 1915.

minute quantities were removed and the exchange of ions between the plant and solution was not excluded from consideration. The researches of Nathanson<sup>7</sup> show the possibility of such an exchange. For example, the absorption of NO<sub>3</sub> by certain algae may be accompanied by a loss of Cl from the plant. Nathanson emphasizes the necessity of a state of equilibrium in the solution and it is self-evident that the equivalence of positive and negative ions must be maintained. Thus, if K is to be selectively absorbed from a KCl solution it must be as KOH, with a residue of HCl. The determinations of reaction and analyses of residual solutions are not in favor of this mechanism. It would seem the final result must be either the equivalent absorption of both ions or the exchange of ions between plant and solution. In a complex nutrient solution or in the soil unlimited possibilities of combination exist.

It is true of course that much evidence has been adduced by Pantanelli, Nathanson and others in support of the hypothesis of the absorption of ions as such, but no evidence obtained from a study of the nutrient solution seems capable of conclusively demonstrating the precise mechanism of the intermediate steps in the absorption. In this general connection the universally known work of Loeb and Osterhout bearing on the ionic nature of antagonism will be recalled. In any case, whether molecular or ionic absorption or ionic exchange is concerned the resultant solutions do not attain a concentration of H ion or OH ion indicative of the presence of highly dissociated acids or bases, while in complex nutrient solutions an approximately neutral reaction is produced as a result of absorption by the plant.

## II

The nature of acid soils and their relation to crop growth have been among the topics most widely discussed by soil chemists. The common occurrence of soils distinctly acid (in the physical chemical sense) has been pointed

<sup>7</sup> Nathanson, A., *Jahrb. f. wissen. Botanik*, Vol. 38, pp. 241-290, 1902-03; Vol. 40, pp. 403-442, 1904; Vol. 39, pp. 607-644, 1903-04.

out by Gillespie<sup>8</sup> and by Sharp and the author.<sup>4,9</sup> Recently Plummer<sup>5</sup> has confirmed these views and presented much additional data. It is often assumed that most agricultural plants require a slightly alkaline reaction in the soil. Previous work has shown that a reaction of  $P_H$  5.0 is in no way inhibitive to the growth of barley seedlings. This point has been investigated further, with the use of several varieties of beans in sand cultures. The solutions were changed with sufficient frequency to maintain constantly an acid reaction. No evidence of injury was apparent. Truog<sup>10</sup> upholds the view that the acidity per se is not ordinarily the limiting factor in acid soils.

With reference to the latter point it may be of interest to present some observations made on an area of California peat soils. All were found to be decidedly acid, as follows:

TABLE IV  
 $P_H$  of Soil Suspensions

Description of Soil	$P_H$
1. Surface, never cropped .....	5.4
1a. Subsoil from above .....	6.0
2. Surface, cropped 15 years .....	4.9
2a. Subsoil from above .....	4.9
3. Surface, 2 years in potatoes .....	5.1
3a. Subsoil from above .....	4.6
4. Surface, barley field .....	4.5

In sections where other inhibiting factors were absent first class crops of barley, oats, beans, potatoes, onions, corn, asparagus, etc., were produced. Incidentally it may be mentioned that from 100 to 3,000 p.p.m. of  $NO_3$  (basis of dry soil) were found. It is evident that in these soils the acid reaction did not interfere with the growth of crops nor the formation of nitrates.

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<sup>8</sup> Gillespie, L. J., *Jour. Wash. Acad. Sci.*, Vol. 6, No. 1, pp. 7-16.

<sup>9</sup> Hoagland, D. R., and L. T. Sharp, *Jour. Agr. Res.*, Vol. XII, No. 3, pp. 139-148, 1918.

<sup>10</sup> Truog, E., *Soil Science*, Vol. 5, No. 3, pp. 169-196, 1918.

#### AN ELECTRO-THERMO-REGULATOR FOR WATER BATHS

THE majority of electro-thermostats so far devised and in use in paraffin ovens, incubators and control chambers have been constructed to operate directly in the chamber itself. Such installation is not wholly desirable, inasmuch as a regulator so placed is subjected to sudden and extreme variations of temperature each time the door or compartment is opened. This not only interferes with the stability and accurate operation of the instrument itself, but causes an unnecessary number of "makes" and "breaks" on the part of the mechanism, with its attendant corrosion of the contact points, and is also conducive to fluctuations in the temperature caused by the unnecessary heating and slow cooling of the heating element. The thermo-regulator herewith described is designed to be inserted in the tubulation of the incubator, where it is immersed in the water of the water jacket. It is intended to be used in connection with a secondary switch in circuit with an electric heating element. So employed, and with a moderate current passing through the primary circuit, the thermostat will give continuous control within a fraction of a degree of the specified temperature.

The thin brass casing *C* is 29.5 cm. long by 2.5 cm. outside diameter. It is strengthened at its upper end by a collar *D*, which extends on one side to form a rigid arm *A*. Binding posts *B* and *B'* are for wires leading to the secondary switch, which is placed in some out-of-the-way situation. They are thoroughly insulated from the arm *A* by red fiber composition. Binding post *B'* is bolted securely to a curved saddle-piece *S*, in which is suspended a bent lever *L*. Platinum points *P* and *P'* of generous size are soldered to binding post *B* and lever *L* respectively, while a no. 3 cover glass *T* is cemented with hard shellac to the vertical arm of the lever, insulating it from the rest of the mechanism.

The thermostat operates on the principle of the unequal expansion of two different metals composing a couple. Zinc and iron make a sensitive combination; but lead and iron, alu-